Q 14: Precision Measurements and Metrology II (with A)

Time: Monday 14:30–16:30 Location: P/H1

Group Report Q 14.1 Mon 14:30 P/H1

Quantum atom optics: states, schemes and applications

— •Helmut Strobel, Daniel Linnemann, Arno Trautmann, Tobias Rentrop, Wolfgang Muessel, Philipp Kunkel, Sören Bieling, Fabian Olivares, Marcell Gall, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, Heidelberg

We report on the generation of non-Gaussian (NG) spin states via unstable fixed point dynamics in mesoscopic ^{87}Rb spinor Bose-Einstein condensates. We present a general method to extract the Fisher information, which reveals entanglement in a regime where no spin squeezing is present. The applicability of the detected quantum resource is explicitly confirmed by the implementation of a Bayesian phase estimation protocol [1].

A different class of NG spin states is generated via spin changing collisions involving three Zeeman sublevels, analogous to parametric down-conversion in quantum optics. Since this process is coherent, it can be utilized as active beam splitters in an interferometer. We characterize the phase-dependent output signal and find a phase sensitivity beyond the classical limit for average atom numbers as small as ~ 1 per side mode inside the interferometer.

We also present recent results in motional interferometry of Lithium impurities immersed in a background of Bose-condensed Sodium for the extraction of small changes of their effective mass. We confirm predicted Feshbach resonances for the interaction of ^{23}Na with ^{7}Li which is a prerequisite for systematic studies of the impurity mass.

[1] H. Strobel *et al.* Science **345** 424-427 (2014)

Q 14.2 Mon 15:00 P/H1

Ultrasensitive magnetometer using a single atom

— •Ingo Baumgart[1], Jianming-M. Cai[2], Alex Retzker[3], Martin B. Plenio[4], and Christof Wunderlich[1] — [1]Department Physik, Naturwissenschaftlich-Technische Fakultät, Universität Siegen, 57068 Siegen, Germany — [2]School of Physics, Huazhong University of Science and Technology, Wuhan 430074, China — [3]Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 91904, Givat Ram, Israel — [4]Institut für Theoretische Physik, Universität Ulm, 89069 Ulm, Germany

Precision sensing [1], and in particular high precision magnetometry [2], is a central goal of research into quantum technologies. The precision, and thus the sensitivity of magnetometry scales as $1/\sqrt{T_2}$ with the phase coherence time, T_2, of the sensing system playing the role of a key determinant. Adapting a dynamical decoupling scheme that allows for extending T_2 by orders of magnitude [2] and merging it with a magnetic sensing protocol, we achieve a measurement sensitivity close to the standard quantum limit. Using a single atomic ion as a sensor, we experimentally attain a sensitivity of 4 pT $\mathrm{Hz}^{-1/2}$ for an alternating-current (AC) magnetic field near 14 MHz. Based on the principle demonstrated here, this unprecedented sensitivity combined with spatial resolution in the nanometer range and tuneability from direct-current to the gigahertz range could be used for magnetic imaging in as of yet inaccessible parameter regimes. [1] Giovannetti, V. et al. *Nat. Photon.* **5,** 222 (2011). [2] Balasubramanian, G. et al. *Nature* **455,** 648 (2008). [3] Timoney, N. et al. *Nature* **476,** 185 (2011).

Q 14.3 Mon 15:15 P/H1

Nanoscale magnetic field sensing enhanced by repeated quantum error correction

— •Thomas Unden[1], Priya Balasubramanian[1], Daniel Louzon[1,4], Yuval Vinkler[4], Martin B. Plenio[2], Matthew Markham[5], Daniel Twitchen[5], Mikhail D. Lukin[3], Alex Retzker[4], Boris Naydenov[1], and Fedor Jelezko[1] — [1]Institut für Quantenoptik, Universität Ulm, 89089 Ulm — [2]Institut für theoretische Physik, Universität Ulm, 89089 Ulm — [3]Quantum Optics Laboratory , Harvard University, 02138 Cambridge — [4]The Racah Institute of Physics, Hebrew University of Jerusalem, 91904 Jerusalem — [5]Element 6

Coherent control of quantum systems offers unique possibilities for precise sensing and metrology. Examples of such well controlled systems are spins associated with single colour centers in diamond that were shown to be promising electric and magnetic field sensors at the nanoscale. The performance of a sensing technique is related to its ability to acquire a phase and to its capacity to reduce perturbations caused by environmental noise. State of the art techniques, however, can only tackle low frequency noise and are thus unable to support sensing of signals in a wide range of settings. Here we experimentally demonstrate for the first time a novel technique of magnetic field sensing enhanced by quantum error correction protocols, which can tackle noise at any frequency, using an electron spin in diamond associated with a single nitrogen-vacancy (NV) center.

Q 14.4 Mon 15:30 P/H1

Highly sensitive magnetic fields sensing with the nitrogen vacancy center in diamond by using the rotary echo scheme

— •Alexander Stark[1,3], Xi Kong[1], Vagharsh Mkhitaryan[2], Viatcheslav Dobrovitski[2], Ulrik L. Andersen[3], and Fedor Jelezko[1] — [1]Institut für Quantenoptik, Universität Ulm, 89081 Ulm, Germany — [2]Ames Laboratory, Iowa State University, Ames, Iowa 50011, USA — [3]Department of Physics, Technical University of Denmark, Fysikvej, 2800 Kgs. Lyngby, Denmark

Single defect centres in diamond and especially the nitrogen-vacancy (NV) show remarkable physical properties making them ideal candidates for single photon sources, qubits and nano-scale magnetic field sensors [1]. In a continuous decoupling protocol [2] the electron spin of the NV center is subjected to continuous Rabi driving with a periodically alternating phase forming the Rotary Echo (RE) scheme [3]. We show that this technique improves greatly the resolution for magnetic field sensing (by a factor of 10) compared to conventional dynamical decoupling techniques [4]. We believe, that RE is one of the promising candidates for the detection of individual nuclear spins in the emerging field of diamond magnetometry.

[1] M. Doherty et al., *Physics Reports* **528**, 1 (2013)
[2] M. Hirose et al., *Physical Review A* **86**, 062320 (2012).
[3] V.V. Mkhitaryan et al., *arXiv*:**1403**.6446 (2014).
[4] C. D. Aiello et al., *Nature Communications* **4**, 1419 (2013).

Q 14.5 Mon 15:45 P/H1

Coherent Quantum Noise Cancellation

— •Daniel Steinmeyer[1,3], Maximilian H. Wimmer[1,3], Klemens Hammerer[1,2], and Michèle Heurs[1,3] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover, Hannover, Germany — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, Hannover, Germany — [3]Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Hannover, Germany

Optomechanical detectors have reached the standard quantum limit in position and force sensing where measurement backaction noise starts to be the limiting factor for the sensitivity. A strategy to circumvent measurement backaction and surpass the standard quantum limit has been suggested by M. Tsang and C. Caves [Phys. Rev. Lett. 105, 123601 (2010)]. We provide a detailed analysis of this method and assess its benefits, requirements, and limitations. We conclude that a proof-of-principle demonstration based on a micro-optomechanical system is demanding but possible. First steps towards such an experiment will be reported.

Q 14.6 Mon 16:00 P/H1

Investigation of high-precision phase estimation in the presence of noise.

— •Sanah Altenburg, Sabine Wölk, and Otfried Gühne — Department Physik, Universität Siegen, Siegen, Germany

Quantum correlation based measurement strategies can overcome classical precision bounds. However, quantum correlation are affected by noisy environments, which ruin the enhancement in precision.

In this talk, we discuss the effect of noisy environments in quantum metrology for different initial preparations of the measurement apparatus. We will concentrate on trapped ions as measurement apparatus. Typical decoherence processes in such systems are collective and distance dependent phase noise. For such decoherence processes, we investigate the maximally reachable precision and determine optimal probe states. Our results can help to improve the precision of experimental setups.

Q 14.7 Mon 16:15 P/H1

Setup to Measure the Coefficient of Thermal Expansion (CTE) of Ultra Stable Materials at Temperature Range from 100K to 300K

— •Rick Burow[1], Ruven Spannagel[1], Thilo

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For space and terrestrial applications dimensionally highly stable materials are needed, e.g. to enable precise measurements. This property of the ultra stable materials, like glass-ceramics or composite materials, is characterized by the Coefficient of Thermal Expansion (CTE). Space applications, like optical systems or sensors, often have a wide operating temperature range, where the CTEs of used materials have to be determined also at cryogenic temperatures. The basic of our setup is a heterodyne laser interferometer, that measures length variations of the sample caused by temperature changes. Our setup is an improvement of the existing facility at room temperature and allows to define CTEs at the temperature range from 100K to 300K. The mechanical and thermal design were improved, due to new requirements. The reached accuracy at room temperature is 10ppb/K, which is also the goal for the new setup.